



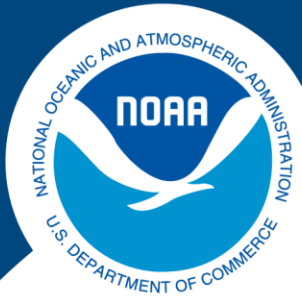
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Bloom or bust: synchrony in jelly abundance, fish consumption, benthic scavenger abundance, and climate across a continental shelf

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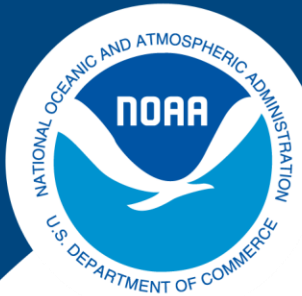


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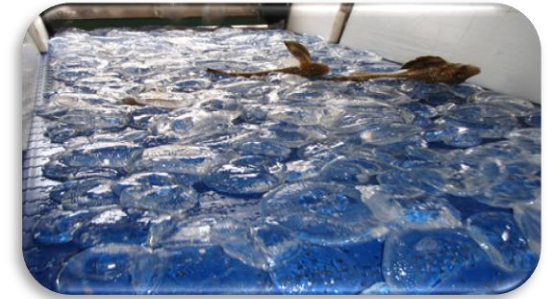
Gelatinous Zooplankton (GZ):
ctenophores, scyphozoans,
salps, and siphonophores

Major Objectives

- Relate common trends in regional gelatinous zooplankton (GZ) abundance of the NE US continental shelf to the fish community and climate change:
 1. Annual GZ consumption by spiny dogfish (*Squalus acanthias*);
 2. Benthic scavenger abundance (n/tow) for Atlantic hagfish (*Myxine glutinosa*) and grenadiers (Macrouridae);
 3. Climate variables: AMO, NAO, sea surface temperature (SST), and bottom temperature (BT).



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Jelly tow

Rationale

- Global concern for increases in GZ populations, their dominance of ecosystems, and their questionable trophic value.
- Notable reoccurrences of GZ blooms; albeit these pulses are also believed to be natural.
- Much work on GZ interactions; how fish communities respond to recurring GZ blooms over large sampling scales is less known.



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Seaweed bloom, China

Rationale

- Organismal blooms come in many marine and freshwater forms (e.g. seaweed, cyanobacteria, and GZ) with ecological and economic consequences.
- Increases in GZ shown to modify fish behavior: limiting grazing frequency of herbivores, and providing an energy reward of gonadic tissue.
- Recent interest in “jelly-falls” and the outcome of bloom carbon.



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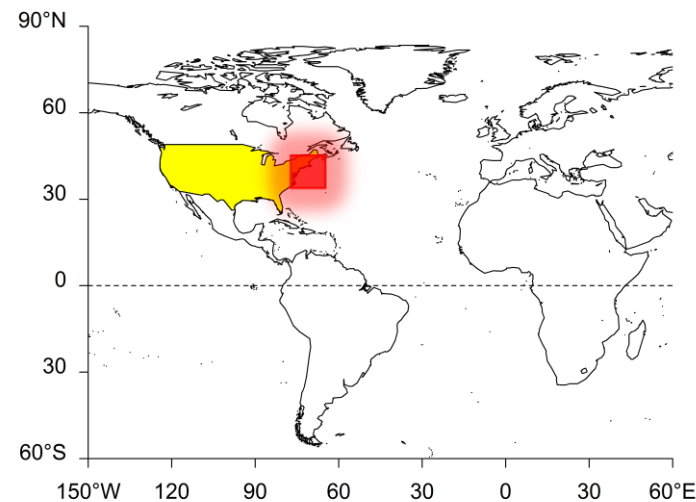
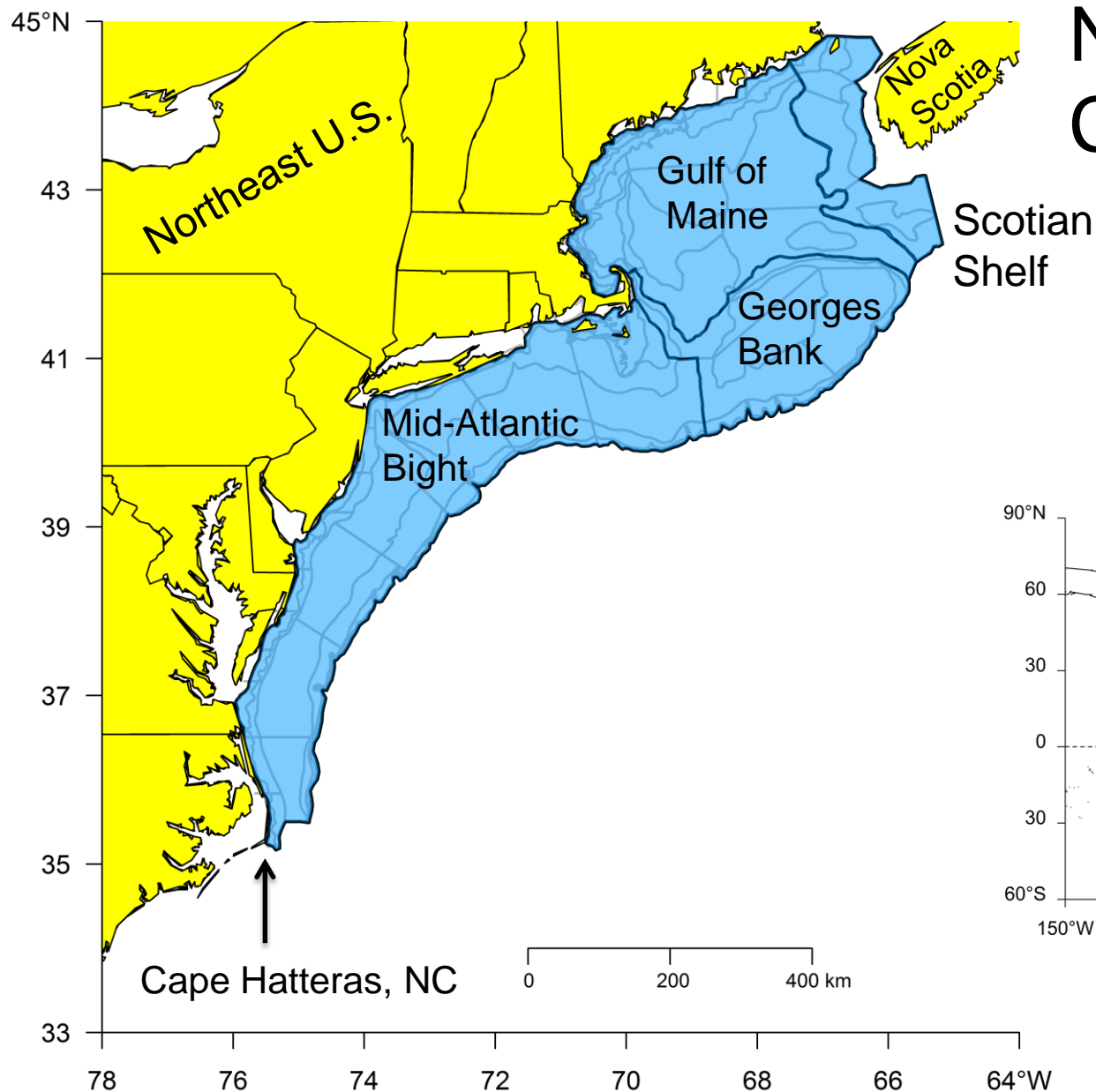


Plankton nets

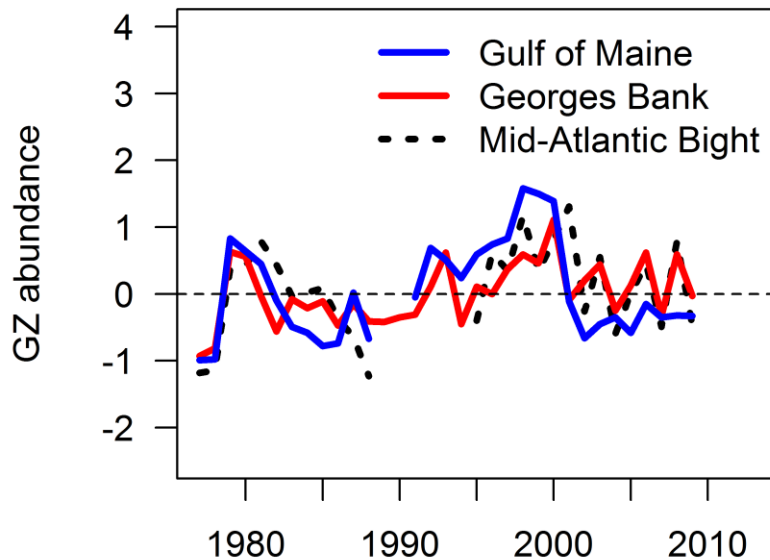
Available Data

- GZ abundance: annual time series of abundance for 3 shelf-regions from NMFS seasonal Ecosystem Monitoring Survey, 1977-2009.
- Spiny dogfish consumption: annual time series of GZ consumption from NMFS seasonal bottom trawl survey, 1977-2013.
- Benthic scavenger abundance: annual time series of hagfish and grenadier abundance per tow from NMFS seasonal bottom trawl survey, 1977-2013.
- Climate indices: annual time series of AMO, NAO, SST, and BT from NOAA NWS and ESRL, and NMFS seasonal bottom trawl survey, 1977-2013.

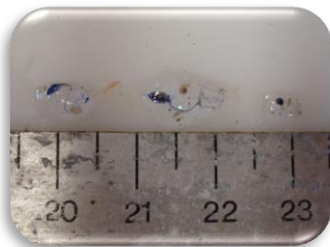
Northeast U.S. Continental Shelf



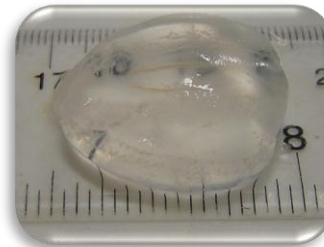
Gelatinous Zooplankton Abundance



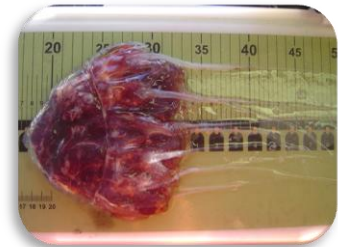
- Values expressed as annual averages of monthly anomalies.
- Blooms: late-1970s to early 1980s and mid-1990s to early 2000s.
- 10-15 year periods.



Salps



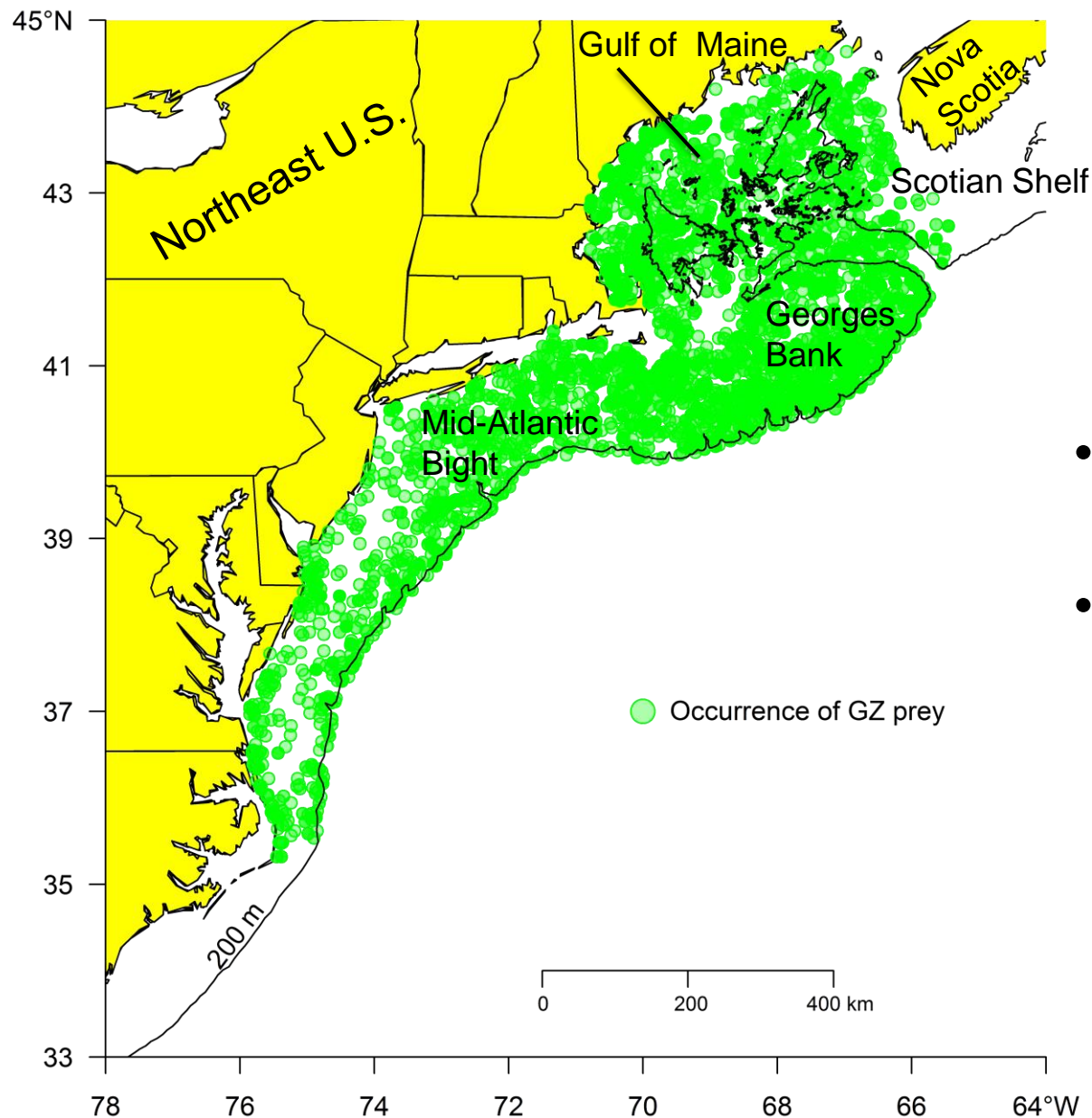
Ctenophore



Scyphozoan

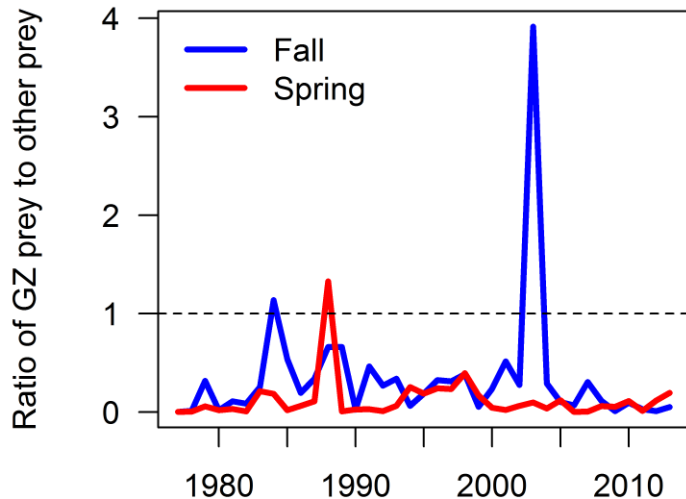
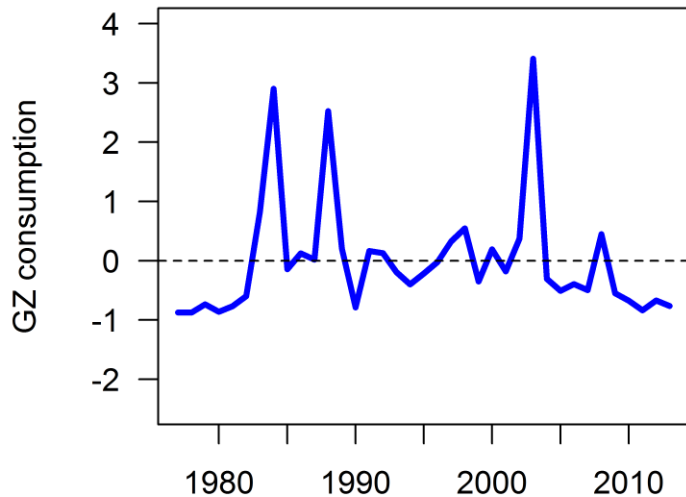
Spiny Dogfish Feeding on Gelatinous Zooplankton

- Widespread occurrences.
- Primary GZ feeder sampled.



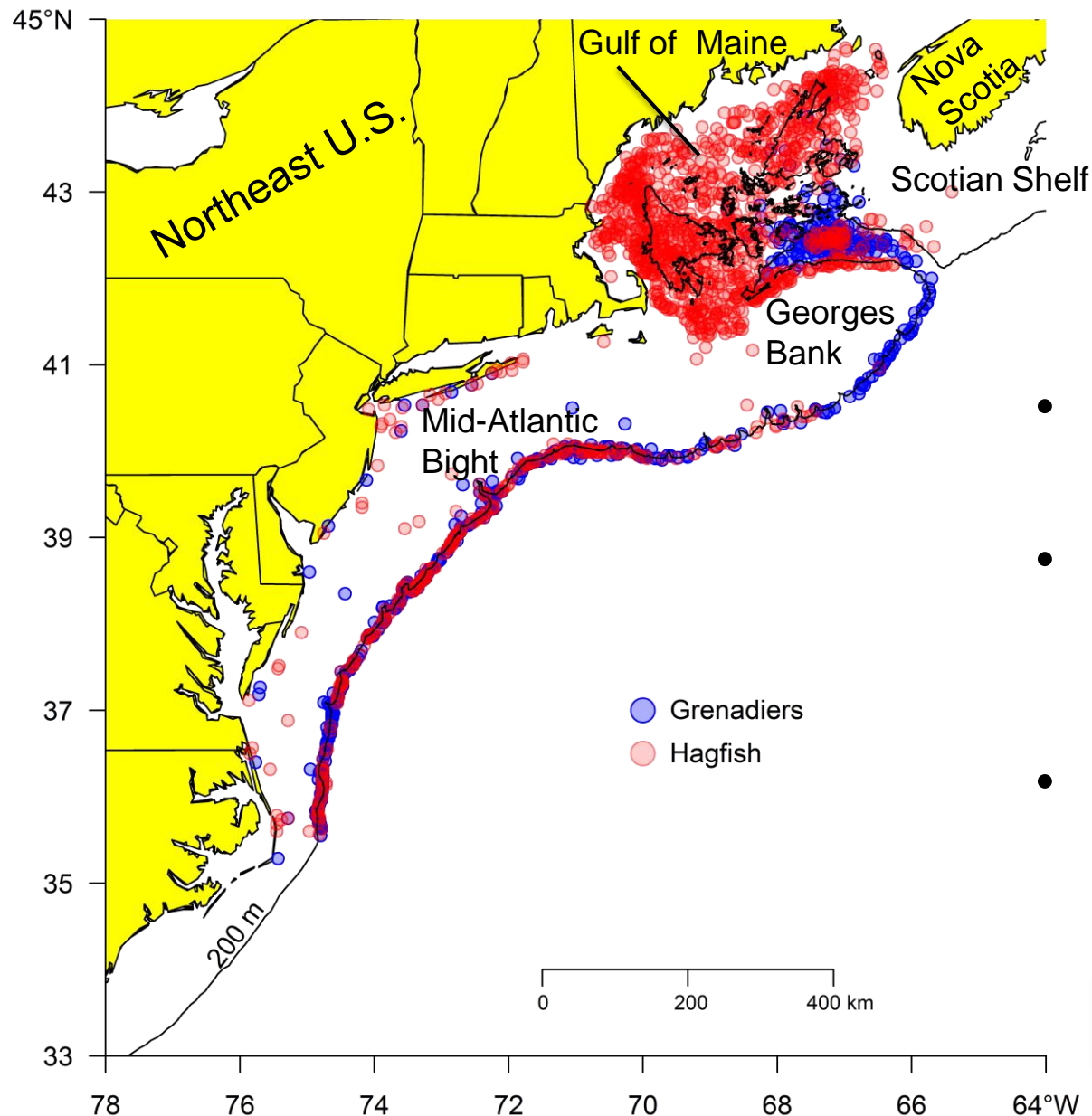
Spiny Dogfish

Consumption of Gelatinous Zooplankton



- Consumption estimated with evacuation rate methods; scaled to annual averages of seasonal anomalies (g/individual).
- 3 major feeding events in 1984, 1988, and 2003.
- GZ consumed was 4-5 times greater vs time series mean.
- GZ are dominant prey following blooms.

Benthic Scavenger Distributions



- 2 well-known fish scavengers.
- Associated with food-falls or feed on jelly-carrion experimentally.
- Shelf edge and GOM.

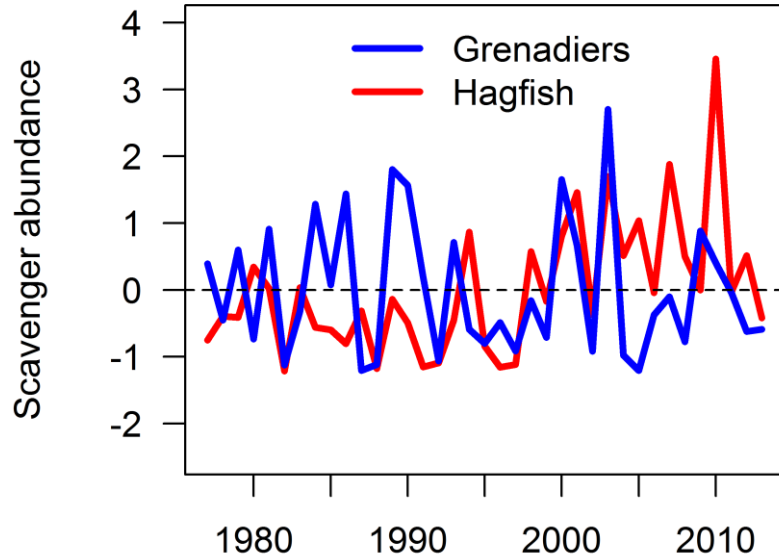


Grenadier



Hagfish

Benthic Scavenger Abundance

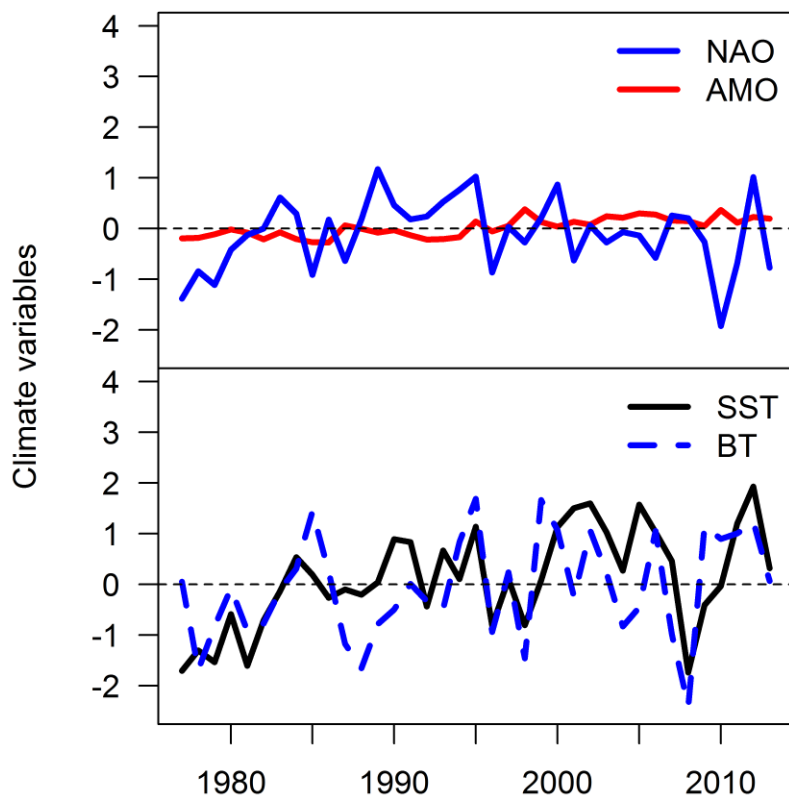


- Abundance estimated as stratified mean n/tow.
- Annual anomalies from the fall bottom trawl survey.
- Hagfish: increased abundance in 1980 and from late 1990s to 2000s.
- Grenadiers: variable abundance early, then increase in late 1990s to early 2000s.



Climate Variables

- AMO, NAO, SST, and BT; annual averages of monthly or seasonal anomalies.
- AMO driven by thermohaline circulation.
- NAO driven by atmospheric pressure.



- AMO: lows <1995 and highs 1995+.
- NAO: more variable, highs 1990s, lows early and late.
- Average SST and BT values were negative <1995 and positive 1995+.
- BT had higher variability.

Time Series Modeling

- Dynamic linear model of GZ Abundance.

$$y_t = Zx_t + n_t \text{ where } n_t \sim \text{MVN}(0, R)$$

$$x_t = x_{t-1} + e_t \text{ where } e_t \sim \text{MVN}(0, Q)$$

$$x_0 = 0$$

y_t = GZ abund. at time (t) by region.

x_t = hidden trend at time (t).

Z = factor loading.

e_t and n_t = respective error.

Q and R = error covariance matrices.

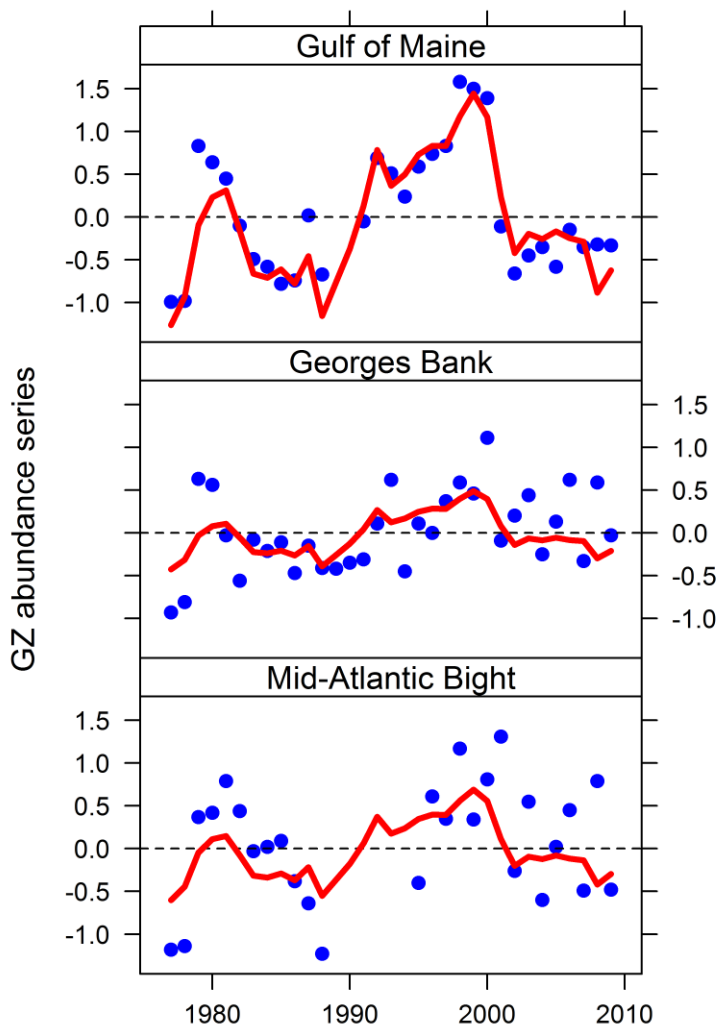
- Non-stationary data
- Missing data
- Dynamic factor analysis
- Common trends
- Dimension reduction
- Add explanatory variables
- Maximum likelihood

Identifying Trends and Relating Expl. Variables

Model	AICc	Δ_i	w_i
1 Data = 1 trend + error	132.4	19.0	0.00005
2 Data = 1 trend + 2-year lagged consump. + error	120.9	7.5	0.01582
3 Data = 1 trend + AMO + error	130.9	17.5	0.00011
4 Data = 1 trend + SST + error	133.2	19.8	0.00003
5 Data = 1 trend + 2-year lagged consump. + AMO + SST + error	119.5	6.1	0.03186
6 Data = 1 trend + 2-year lagged hagfish abund. + error	130.7	17.3	0.00012
7 Data = 1 trend + 2-year lagged grenadier abund. + error	130.3	16.9	0.00014
8 Data = 1 trend + 2-year lagged consump. + 2-year lagged hagfish abund. + 2-year lagged grenadier abund. + error	117.2	3.8	0.10063
9 Data = 1 trend + 2-year lagged consump. + AMO + 2-year lagged hagfish abund. + 2-year lagged grenadier abund. + error	119.9	6.5	0.02609
10 Data = 1 trend + 2-year lagged consump. + SST + 2-year lagged hagfish abund. + 2-year lagged grenadier abund. + error	113.4	0.0	0.67283
Combinations not shown	> 117.5	NA	NA

- 1 common trend identified across shelf (model # 1).
- 2-year lagged spiny dogfish consumption and scavenger abundance.
- SST and AMO.
- AMO related to GZ abundance, but not substantial.
- Lowest AICc model included lagged consumption, lagged hagfish abundance, lagged grenadier abundance, and SST (model # 10).

Modeling Gelatinous Zooplankton Abundance



- Accepted model #10.
- GZ abundance characterized by 4 events.
- Bloom periods: ~early 1980s, and early 1990s through early 2000s.
- Low abundance: 1980s and 2000s.



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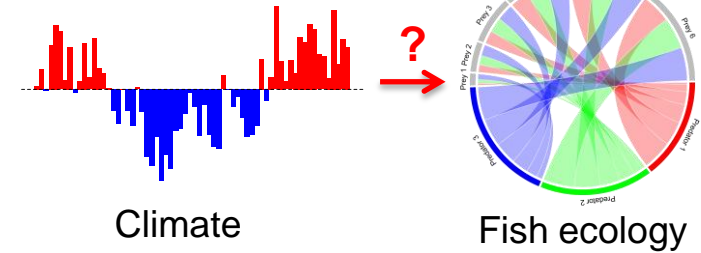


Summary

- Approximately 10-15 year periods in GZ abundance.
- Patterns tied to fish community via feeding and benthic scavenger abundance as a proxy for fish productivity.
- GZ blooms provide surges of food for spiny dogfish (dominant prey) and are a potential carbon source for benthic scavengers (food-falls or additional resources).

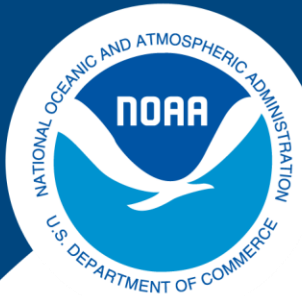


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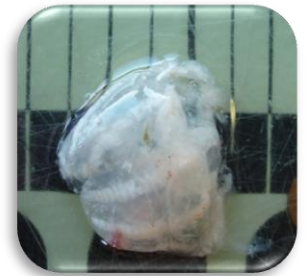


Summary

- GZ bloom periods were positively related to changes in SST.
- Example of a feeding response due to climate change via the plankton community.
- Other 'samplers' provide valuable information on trends in GZ abundance and the utility of plankton thought to have minimal ecosystem value.



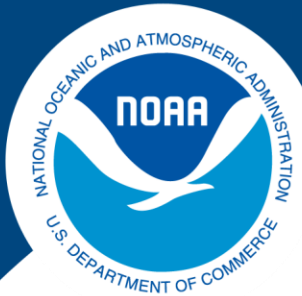
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Digested ctenophore

Discussion

- Synchrony in bloom timing and fish community dynamics; link lower and upper trophic levels; strong couplings between GZ and benthos.
- Notable trophic value of GZ following blooms.
- 2-year lag in fish community responses possibly due to sampler differences, GZ longevity, feeding thresholds, and scavenger response time.



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Discussion

- Energetic tradeoffs of fishes following bloom years (prey switching vs additional energy).
- GZ are not ignored in this ecosystem. Carbon moved throughout the food web and between photic and aphotic environments.
- Monitoring GZ and including them in ecosystem models will provide better system understanding due to their profound yet variable effects.



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Questions?



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